

Vertical variation and storage of nitrogen in an aquic brown soil under different land uses

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Abstract: The vertical variation and storage of nitrogen in the depth of 0-150 cm of an aquic brown soil were studied under 14 years of four land use patterns, i.e., paddy field, maize field, fallow field and woodland in Shenyang Experimental Station of Ecology, Chinese Academy of Sciences in November of 2003. The results showed that different land uses had different profile distributions of soil total nitrogen (STN), alkali N, ammonium ($\text{NH}_4^+\text{-N}$) and nitrate ($\text{NO}_3^-\text{-N}$). The sequence of STN storage was woodland > maize field > fallow field > paddy field, while that of $\text{NO}_3^-\text{-N}$ content was maize field > paddy field > woodland > fallow field, suggesting the different root biomass and biological N cycling under various land uses. The STN storage in the depth of 0-100 cm of woodland averaged to $11.41 \text{ t} \cdot \text{hm}^{-1}$, being 1.65 and 1.25 times as much as that in paddy and maize fields, respectively, while there was no significant difference between maize and fallow fields. The comparatively higher amount of $\text{NO}_3^-\text{-N}$ in maize and paddy fields may be due to nitrogen fertilization and anthropogenic disturbance. Soil alkali N was significantly related with STN, and the correlation could be expressed by a linear regression model under each land use ($R^2 \geq 0.929$, $p < 0.001$). Such a correlation was slightly closer in nature (woodland and fallow field) than in agro ecosystems (paddy and maize fields). Heavy N fertilization induced an excess of crop need, and led to a comparatively higher amount of soil $\text{NO}_3^-\text{-N}$ in cultivated fields than in fallow field and woodland. It is suggested that agroforestry practices have the potential to make a significant contribution to both crop production and environment protection.

Keywords: Aquic brown soil; Land use; Soil nitrogen storage; Vertical variation

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Introduction

Nitrogen (N) cycling has long been the subject of intense scientific investigation, because understanding the translocation and transformation of this element is the basis of solving many environmental, agricultural and natural resource problems (Brady and Weil 2002). Recent concerns about N as a major source of eutrophication in streams and lakes are focused on the earth's N cycling. About 95%-99% soil N is in organic form that protects itself from loss but leaves it largely unavailable to higher plants. The oxidation of soil organic matter together with the application of inorganic fertilizer tends to make cultivated lands as the source of N emissions (Cambardella and Elliott 1994), but in contrast, grasslands (Adger *et al.* 1992; Potter *et al.* 1999), young growing forests (Thuille *et al.* 2000) and agroforests (Kaur *et al.* 2000) tend to accrete more soil organic matter over time. Forests are often favored for N sequestration,

because of their ability to accumulate large amounts of organic matter in woody biomass and decay-resistant litter. However, nitrogen in available form is highly mobile in soil and environment, and hence, soil bio-available N in agroecosystems may differ from that in natural ecosystems. Chikowo *et al.* (2004) reported that nitrate could accumulate at the soil depth below 40 cm during early season when maize had not developed a sufficient root density to effectively capture nutrients. Many studies about soil N distribution and soil total nitrogen (STN) storage were on the conversion of forest or grassland to cultivated land (e.g., Kaur *et al.* 2000; Kaur *et al.* 2002), but seldom on that of cultivated land to other land uses. Furthermore, information about soil bio-available N under different land uses in a small scale was limited. Just for these, we chose Shenyang Experimental Station of Ecology, Chinese Academy of Sciences as the study site, and studied the profile distributions of soil total N (STN), alkali N (AN), $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ and the STN storage in different lands, aimed at understanding the dynamics of soil N under different land use, and to provide scientific basis for soil N management.

Materials and methods

Site description

The Shenyang Experimental Station of Ecology, Chinese Academy of Sciences, is situated at the lower reaches of

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Liao River Plain (123°22'E, 41°31'N). It is located in the continental temperate monsoon zone, with a dry-cold winter and a warm-wet summer. The mean annual temperature is 7.0-8.0°C, annual precipitation is 650-700 mm, and the frost-free period is 147-164 d. The soil is classified as ac- quic brown soil (Hapli-Udic Cambosols in Chinese Soil Taxonomy, CRGCST 2001), with a deep thickness of pedon and Fe-Mn mottlings. The cultivated horizon is loamy, with an apparent plowpan, and the substratum is clayey and tight. Before the establishment of the Station in 1989, all the lands were paddy field with comparatively homogeneous fundamental soil fertility, and after 1989, part of the lands

was turned into maize field, fallow field, and woodland.

Soil sampling

In November 2003, soil samples were collected from four types of land use patterns, i.e., paddy (*Oryza sativa* L.) field, maize (*Zea mays* L.) field, fallow field, and woodland (*Populus canadensis*), respectively. Three replicated pro- files for each land use pattern were excavated in depth of 0-150 cm, which were divided into 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-120, and 120-150 cm layers. Descriptions of the sampling sites were shown in Table 1.

Table 1. Description of sampling sites

Sample No.	Land use pattern	Years	Latitude (N)	Longitude (E)	Remarks
1	Paddy field	>14	31°12"	22°11"	Annul application rate of urea, (NH ₄) ₂ HPO ₄ and KCl was 450, 150, and 112.5 kg·hm ⁻² , respec- tively.
2	Paddy field	>14	31°07"	22°00"	
3	Paddy field	>14	31°06"	22°00"	
4	Maize field	14	31°09"	21°58"	Annul application rate of urea, (NH ₄) ₂ HPO ₄ and KCl was 300, 150 and 75 kg·hm ⁻² , respectively.
5	Maize field	14	31°10"	21°58"	
6	Maize field	14	31°08"	21°58"	
7	Fallow field	9	31°15"	21°59"	Maize was planted in 1990-1994, and fallowed after 1995.
8	Fallow field	9	31°16"	21°59"	
9	Fallow field	9	31°16"	21°58"	
10	Woodland	14	31°14"	22°04"	Litter layer was about 3 cm in depth.
11	Woodland	14	31°14"	22°05"	
12	Woodland	14	31°15"	22°04"	

Soil physical and chemical analyses

Soil total nitrogen was determined by semi-microkjeldahl method, alkali nitrogen was determined by 24-hour auto-clave-Convey micro-diffusion method, and NH₄⁺-N and NO₃⁻-N were extracted with 2 mol·L⁻¹ KCl and determined by magnesium oxide-devarda alloy method (Page *et al.* 1982). Soil bulk density was determined by using stainless steel ring and oven-dried at 105°C.

Data analysis and calculation of soil organic carbon storage

The obtained data were analyzed with SPSS 10.0, using one-way ANOVA and Duncan's pairwise comparison for means separation. A significance level of $p=0.05$ was chosen for detecting significant differences. Figures were drawn using Microsoft Excel software.

Soil total nitrogen storage was calculated by the following formula:

$$STN = \sum_{i=1}^n (N_i \times \rho_i \times T_i) \times 10^{-1} \quad (1)$$

where STN is the soil total nitrogen storage (t·hm⁻²) at a given depth of T , N_i is the total nitrogen concentration (g·kg⁻¹) of layer i , ρ_i is the bulk density (g·cm⁻³) of layer i , T_i is the thickness (cm) of layer i , and n is the number of lay- ers.

Results and discussion

Profile distribution of soil total nitrogen and its storage

Throughout the depth of 150 cm, the concentration of STN in woodland was highest than those in paddy, maize and fallow fields (Table 2). All the profiles of paddy, maize and fallow fields showed a decreasing trend of STN con- centration with the increase of depth, but in woodland, the STN concentration was more or less fluctuant in the layers below 30 cm, which was higher than that in the corre- sponding layers of the other three land use patterns.

Table 2. Profile distribution of soil total nitrogen under dif- ferent land uses

Depth /cm	Paddy field / g·kg ⁻¹	Maize field / g·kg ⁻¹	Fallow field / g·kg ⁻¹	Woodland / g·kg ⁻¹
0-5	0.97±0.13b	1.03±0.04b	1.71±0.07a	2.19±0.56a
5-10	0.90±0.04a	1.04±0.04a	1.01±0.14a	0.91±0.05a
10-20	0.80±0.06b	0.97±0.02a	0.85±0.10ab	0.87±0.07ab
20-30	0.65±0.11b	0.87±0.02a	0.75±0.06ab	0.79±0.07a
30-40	0.53±0.07b	0.71±0.04a	0.67±0.09a	0.77±0.05a
40-60	0.51±0.13b	0.73±0.03a	0.59±0.12ab	0.72±0.06a
60-80	0.45±0.16c	0.69±0.05ab	0.50±0.15bc	0.79±0.03a
80-100	0.35±0.08b	0.60±0.10a	0.37±0.07b	0.74±0.09a
100-120	0.27±0.05c	0.43±0.06b	0.29±0.08bc	0.60±0.11a
120-150	0.27±0.03b	0.33±0.03b	0.29±0.08b	0.50±0.12a

Note: Mean values of 3 replicates. In a line, figures followed by different letter(s) are significantly different by Duncan's multiple range test ($p \leq 0.05$).

In the layer of 0-5 cm, the concentrations of STN of woodland and fallow field were higher than those of paddy and maize fields; in the layer of 5-10 cm, there was no significant difference among the four land use patterns; while in the layer of 10-20 cm, the STN concentration of maize field was significantly higher than those of the other three land use patterns. The STN concentrations of woodland and maize field in the layer of 20-100 cm were tended to be higher than those of fallow and paddy fields, and below 100 cm, STN concentration of woodland was significantly higher than those the other three land uses.

In general, the order of STN storage was woodland > maize field > fallow field > paddy field (Fig. 1). The STN storage in depth of 0-20 cm in paddy field was significantly lower than those in maize field ($p=0.023$), fallow field ($p=0.004$) and woodland ($p=0.009$), but in depth of 0-100 cm, it was significantly higher in woodland than in any of the other three land use patterns ($p=0.001$, 0.037 and 0.035, as compared to paddy, maize and fallow fields, respectively). The STN storage was also higher in maize and fallow fields than in paddy field. A similar result was found in depth of 0-150 cm, and the p values were 0.001, 0.018 and 0.008, respectively, as compared the STN storage in woodland to that in paddy, maize and fallow fields, respectively.

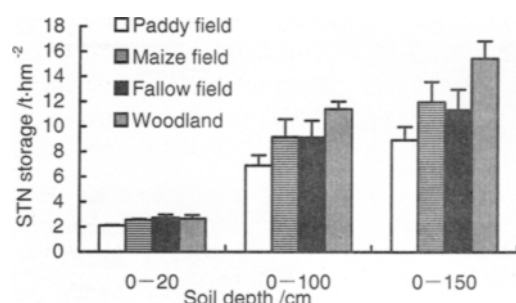


Fig. 1 Soil total nitrogen storage under different land uses

The increased amount of STN in the upper layers of fallow field and woodland could be explained by a high litter production on the fields (Ritter *et al.* 2003). Deciduous tree might result in a higher N level in its litter fall at a given site (Berg and Meentemeyer 2002), e.g., popular tree (*Populus canadensis*) could transfer 21%-25% of N through leaves and litter (Shen *et al.* 1993), and hence, the STN in the upper layer of woodland was comparatively higher. Kaur *et al.* (2002) reported that the association of trees with grasses in the Silvopastoral systems of India revealed an increased input of plant residues into soil, which played a significant role in improving nutrient cycling and biological productivity in the tree based systems. Owing to the increased biological production and the higher C and N storages in vegetation and soil, agroforests might be more efficient than plantations or pasture monocultures in accreting soil C and N (Sharrow and Ismail 2004). According to Ritter *et al.* (2003), in afforested stands, the initially mobilized N could be fixed in the biomass again, which was an

important sink of N in the very early phase of afforestation. N loss might occur when the mobilized N exceeds the amount that can be stored in the biomass (Jug *et al.* 1999). Cultivation generally enhances the microbial decomposition of soil organic C and N. It may also affect soil C and N storages by changing soil redox condition and solution chemistry, or water flowing through soils. The changes of soil redox and solution chemistry have the potential to dissociate the bonds between metals and the organic matter complexed to them (Schwertmann 1988), and thus, to change soil C and N storage (Osher *et al.* 2003). The root biomass of maize is higher than that of rice, and C_4 plant has a significantly higher C/N ratio and a lower N mineralization compared with C_3 plant (Burke *et al.* 1998), which leads to the profile distribution of STN and its storage being higher in maize (C_4 plant) field than in paddy (C_3 plant) field. In short, the differences of the N vertical variation in soil profiles and the STN storages under different land uses might be due to the difference of underground biomass, and the aboveground accumulation of litter or crop residual was also regarded as the important storage apartment.

Profile distribution of soil alkali N, NH_4^+ -N, and NO_3^- -N

Except where large amounts of chemical fertilizers are applied, soil inorganic N seldom accounts for more than 1%-2% of the total N (Brady and Weil 2002). Land use practices may affect the bioavailability of soil N, owing to its various cycling mechanisms under different land uses, and hence, the profile distribution of alkali N, ammonium N and nitrate N is worthy of investigating.

The concentrations of soil alkali nitrogen (AN) in a layer of 0-5 cm in woodland and fallow field were higher than those in paddy and maize fields, but in layers of 5-20 cm, it was significantly higher in maize field than in the other three land use patterns ($p<0.05$), and there was no significant difference (Fig. 2). In layers below the depth of 30 cm, soil AN concentrations in woodland and maize field was tended to be higher than those in paddy and fallow fields. In general, the sequence of AN content in soil profile was woodland > maize field > fallow field > paddy field, which was just the same as that of the STN.

Either in natural or in agro ecosystems, soil AN is closely correlated with STN. In this study, soil AN also had a significant correlation with STN, and the correlation was slightly closer in nature (woodland and fallow field) than in agro ecosystems (paddy and maize fields) (Table 3).

Table 3. Relationships between soil alkali N (AN) and soil total N (STN) ($n=30$)

Land use	Regression model	R	R square	p	Std error
Paddy field	$AN=83.455TN-1.810$	0.964	0.929	<0.001	5.998
Maize field	$AN=97.729TN-10.414$	0.971	0.944	<0.001	5.755
Fallow field	$AN=75.301TN+2.063$	0.987	0.975	<0.001	5.154
Woodland	$AN=66.180TN+8.040$	0.978	0.957	<0.001	6.925

In layers from 0 to 20 cm, soil NH_4^+ -N concentration in

maize field was significantly higher than those in the other three land use patterns. In layers below 20 cm, the concentration was tended to be higher in maize field, while there was no significant difference among paddy field, fallow field and woodland (Table 4). Generally, the sequence

of $\text{NH}_4^+\text{-N}$ content in soil profile was maize field > woodland > paddy field > fallow field, which was quite different from those of STN and AN, indicating a different vertical distribution characteristic. The difference may be due to the anthropogenic disturbance in the two cultivated fields.

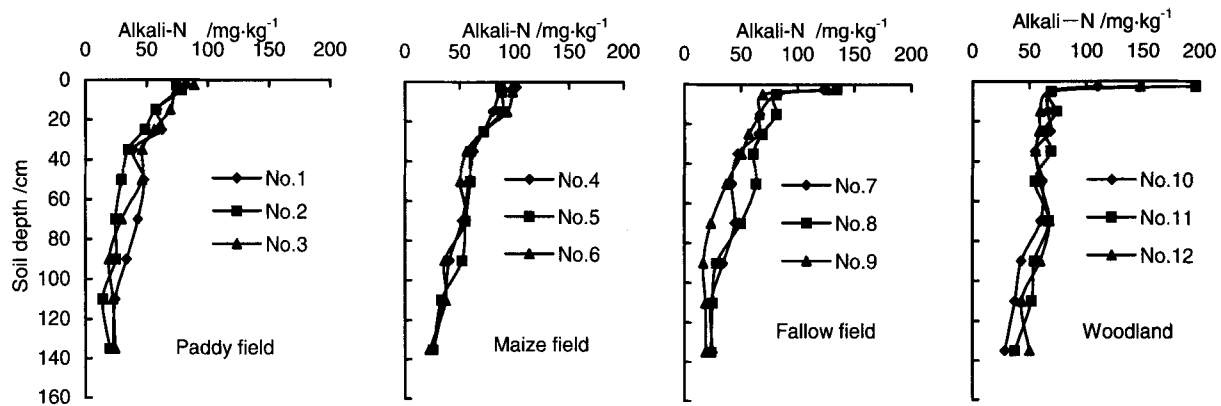


Fig. 2 Vertical variation of alkali N in soil profiles under different land uses

Table 4. Soil $\text{NH}_4^+\text{-N}$ concentration under different land uses

Depth /cm	Paddy field / mg · kg ⁻¹	Maize field / mg · kg ⁻¹	Fallow field / mg · kg ⁻¹	Woodland / mg · kg ⁻¹
0-5	14.01±3.71b	26.92±4.90a	11.36±2.74b	13.70±1.94b
5-10	11.52±1.43b	21.94±2.33a	10.74±2.92b	11.98±1.77b
10-20	13.54±3.37b	20.85±2.30a	10.27±2.47b	12.61±1.24b
20-30	12.45±1.77b	23.66±7.01a	10.74±1.87b	13.85±2.11b
30-40	11.67±0.47c	18.21±0.81a	9.34±0.81d	14.94±0.93b
40-60	13.54±3.65ab	20.85±6.56a	9.81±0.81b	15.41±3.06ab
60-80	13.07±4.04ab	18.83±0.97a	9.81±2.92b	14.01±3.37ab
80-100	9.49±2.16b	16.81±1.62a	10.12±0.71b	13.70±2.30a
100-120	9.81±3.53b	17.74±2.80a	9.18±1.18b	16.03±0.71a
120-150	12.30±0.71bc	21.01±4.94a	9.18±1.50c	17.74±4.04ab

Note: Mean values of 3 replicates. In a line, figures followed by different letter(s) are significantly different by Duncan's multiple range test ($p \leq 0.05$).

Table 5. Soil $\text{NO}_3^-\text{-N}$ concentration under different land uses

Depth /cm	Paddy field / mg · kg ⁻¹	Maize field / mg · kg ⁻¹	Fallow field / mg · kg ⁻¹	Woodland / mg · kg ⁻¹
0-5	15.49±6.88a	15.64±2.92a	6.30±2.04a	8.48±6.02a
5-10	8.33±0.71ab	10.19±1.89a	3.97±1.68b	7.70±3.82ab
10-20	2.88±0.97a	7.24±5.50a	4.12±2.21a	3.04±1.62a
20-30	3.35±0.97a	8.17±5.85a	3.19±1.64a	3.04±2.47a
30-40	2.72±1.35b	9.11±0.81a	1.63±1.40b	3.19±1.35b
40-60	4.12±1.43ab	5.21±1.43a	1.48±1.43b	2.72±1.35ab
60-80	4.59±1.89a	5.53±2.30a	2.10±0.81a	3.19±1.64a
80-100	5.37±0.81a	5.37±0.82a	3.19±1.18a	3.35±2.21a
100-120	4.75±2.11b	8.37±1.18a	2.26±1.64b	3.19±1.64b
120-150	8.79±2.30a	7.39±3.04a	1.95±0.97b	2.72±1.08b

Note: Mean values of 3 replicates. In a line, figures followed by different letter(s) are significantly different by Duncan's multiple range test ($p \leq 0.05$).

The concentration of soil $\text{NO}_3^-\text{-N}$ in maize field was tended to be higher than those in the other three land use patterns throughout the depth of 0-150 cm. In layers 0-5 cm, 5-10 cm and below 40 cm, the concentration in paddy field was tended to be higher than those in fallow field and woodland. The general sequence of $\text{NO}_3^-\text{-N}$ content in soil profile was maize field > paddy field > woodland > fallow field (Table 5), which was quite different from those of STN, AN, and $\text{NH}_4^+\text{-N}$.

Unlike most of soil organic N, soil mineral N forms are mostly quite soluble in water, and may be easily lost through leaching or volatilization. Some mature forest system may achieve a very close balance between plant N uptake and litter N return (Brady and Weil 2002), but in agricultural systems, the N inputs regularly exceed the N amounts removed by crop uptake and harvest. Heavy N fertilization exceeds what the crops are able to utilize, and leads to a comparatively higher amount of $\text{NO}_3^-\text{-N}$ accumulated in cultivated fields than in fallow field and woodland, which may be the major cause of excessive leaching. Fertilization and irrigation practices led to a relatively high $\text{NO}_3^-\text{-N}$ accumulation in deep layers of cultivated fields and N leaching loss (Riley *et al.* 2001). According to Ogotu (1999), C/N ratio is always higher in disturbed soils than in undisturbed forest or grassland soils, and disturbance increases the decomposition and mineralization of soil organic matter, and as a result, leads to the N leaching loss. Long-term N application altered ecosystem properties such as N mineralization, N retention, and $\text{NO}_3^-\text{-N}$ concentrations, likely through the influence of changes in plant productivity and residue quality (Wedin and Tilman 1996). Although the soil $\text{NO}_3^-\text{-N}$ concentration in layers at 0-20 cm depth had no significant difference between maize and paddy fields, the layers below 20 cm depth of paddy field contained com-

paratively lower NO_3^- -N. It is found recently that some of the leached NO_3^- -N from maize field is not in groundwater, but stored in soil profile several meters deep where highly weathered clays have absorbed it on their anion exchange sites (Qafoku *et al.* 2000). Deep-rooted trees are capable of taking up this deep subsoil NO_3^- -N, and subsequently, using it to enrich the surface soil when they shed their leaves (Sanchez *et al.* 1997). On the contrary, rotation of maize with fast-growing N_2 -fixing trees on N-deficient soils (improved fallows) can improve soil fertility and crop yield (Mafongoya and Dzwela 1999). Thus, agroforestry practices may have the potential to make a significant contribution to both crop production and environment production.

Conclusion

After fourteen years of different land uses, the amount of soil total nitrogen (STN) in woodland was higher than those in maize, fallow and paddy fields. Although the STN storage at a depth of 0-20 cm in fallow field was higher than that in maize field, the later tended to store a little more STN than the former at the depths of 0-100 cm and 0-150 cm. Paddy field was regarded to have the least potential to store N. The profile distribution of soil alkali N (AN) had the same pattern as that of the STN under the four land uses, while the sequences of soil NH_4^+ -N and NO_3^- -N contents were quite different from those of the STN and AN. Although the STN in woodland was higher than those in maize and paddy fields, the NO_3^- -N content in woodland was much lower than those in the two cultivated fields, especially in deep soil layers. It is suggested that woodland was a significant N sink with a substantial amount of N captured and stored in soil, and agroforestry practices had the potential to make a significant contribution to both crop production and environment protection by storing N in soil and by lessening NO_3^- -N leaching.

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